High Current Boost Regulator with Load Disconnect

GENERAL DESCRIPTION

The ML4870 is a continuous conduction boost regulator designed for DC to DC conversion in multiple cell battery power systems. Continuous conduction allows the regulator to maximize output current for a given inductor. The maximum switching frequency can exceed 200kHz, allowing the use of small, low cost inductors. The ML4870 is capable of start-up with input voltages as low as 1.8V, and is available in 5V and 3.3V output versions with an output voltage accuracy of ±3%.

An integrated synchronous rectifier eliminates the need for an external Schottky diode and provides a lower forward voltage drop, resulting in higher conversion efficiency. In addtion, low quiescent current and variable frequency operation result in high efficiency even at light loads. The ML4870 requires only a few external components to build a very small regulator capable of achieving conversion efficiencies approaching 85%.

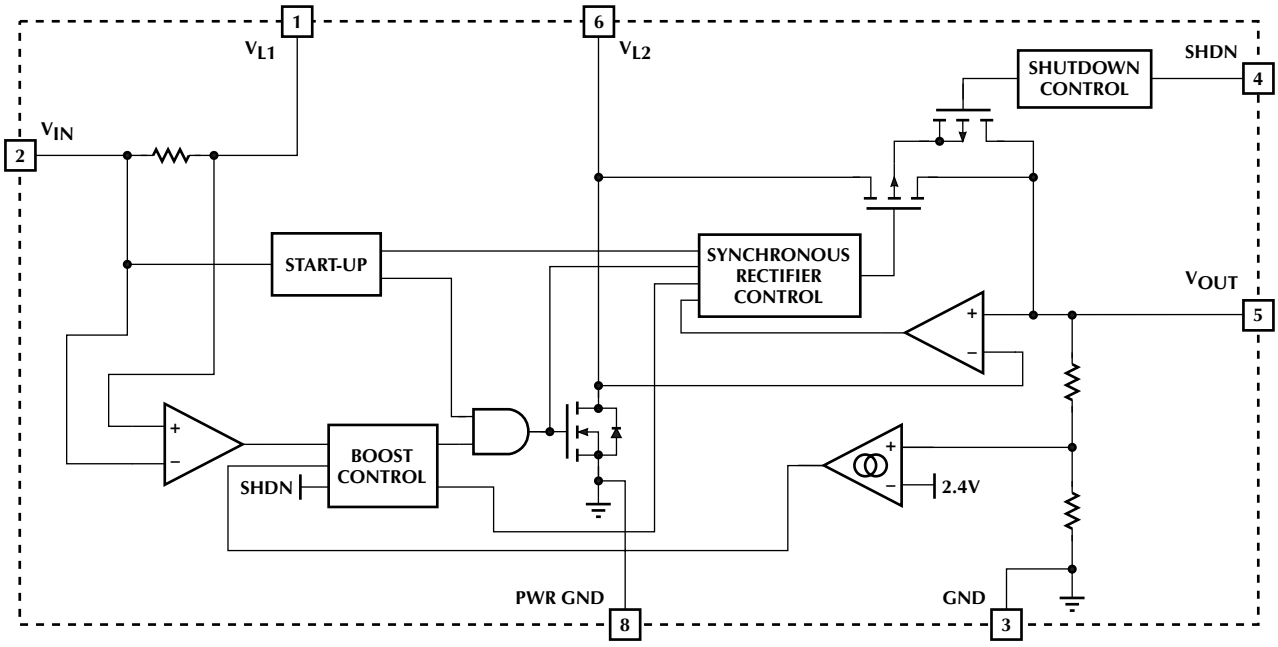
The SHDN input allows the user to stop the regulator from switching, and provides complete isolation of the load from the battery.

FEATURES

- Guaranteed full load start-up and operation at 1.8V input
- Continuous conduction mode for high output current
- Pulse Frequency Modulation and internal synchronous rectification for high efficiency
- Isolates the load from the input during shutdown
- Minimum external components
- Low ON resistance internal switching FETs
- Low supply current
- 5V and 3.3V output versions

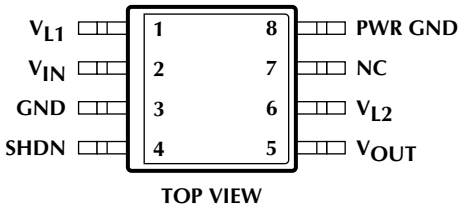
*Some Packages Are Obsolete

BLOCK DIAGRAM



PIN CONFIGURATION

ML4870
8-Pin SOIC (S08)



TOP VIEW

PIN DESCRIPTION

PIN	NAME	FUNCTION
1	V_{L1}	Boost inductor connection
2	V_{IN}	Battery input voltage
3	GND	Ground
4	SHDN	Pulling this pin to V_{IN} shuts down the regulator, isolating the load from the input
5	V_{OUT}	Boost regulator output
6	V_{L2}	Boost inductor connection
7	NC	No connection
8	PWR GND	Return for the NMOS output transistor

ABSOLUTE MAXIMUM RATINGS

Absolute maximum ratings are those values beyond which the device could be permanently damaged. Absolute maximum ratings are stress ratings only and functional device operation is not implied.

V_{OUT} 7V
Voltage on any other pin ..... GND - 0.3V to V_{OUT} + 0.3V
Peak Switch Current (I_{PEAK}) 2A
Average Switch Current (I_{AVG}) 1A
Junction Temperature ..... 150°C
Storage Temperature Range ..... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) ..... 260°C
Thermal Resistance (θ_{JA}) ..... 160°C/W

OPERATING CONDITIONS

Temperature Range
ML4870CS-X ..... 0°C to 70°C
ML4870ES-X ..... -20°C to 70°C
V_{IN} Operating Range ..... 1.8V to V_{OUT} - 0.2V

ELECTRICAL CHARACTERISTICS

Unless otherwise specified, V_{IN} = Operating Voltage Range, T_A = Operating Temperature Range (Note 1)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
SUPPLY							
$I_{IN(Q)}$	V_{IN} Quiescent Current	V_{IN} = V_{OUT} - 0.2V, SHDN = 0V			3	6	µA
		V_{IN} = SHDN = 2.4V, V_{OUT} = 0V			0.3	1	µA
$I_{OUT(Q)}$	V_{OUT} Quiescent Current	SHDN = 0V			25	35	µA
		V_{IN} = SHDN = 2.4V V_{OUT} = $V_{OUT(NOM)}$			14	20	µA
PFM REGULATOR							
I_{PEAK}	I_L Peak Current			1.1	1.3	1.6	A
V_{OUT}	Output Voltage	I_{OUT} = 0	-3 Suffix	3.30	3.35	3.40	V
		See Figure 1	-5 Suffix	4.95	5.05	5.15	V
	Load Regulation	-3 Suffix, V_{IN} = 2.4V, I_{OUT} = 400mA		3.20	3.25	3.40	V
		-5 Suffix, V_{IN} = 2.4V, I_{OUT} = 220mA		4.85	4.95	5.15	V
SHUTDOWN							
V_{IL}	Input Low Voltage					0.5	V
V_{IH}	Input High Voltage			V_{IN} - 0.5			V
	Input Bias Current			-100		100	nA

Note 1: Limits are guaranteed by 100% testing, sampling, or correlation with worst case test conditions.

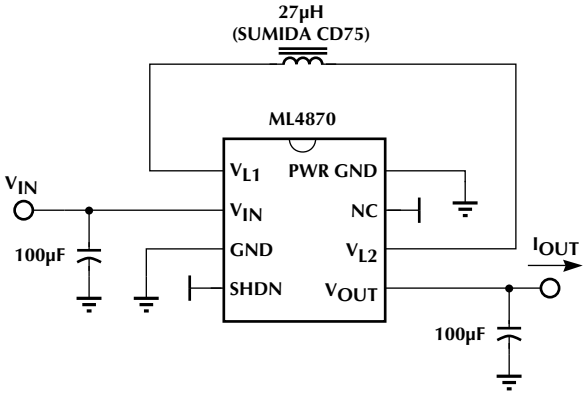


Figure 1. Application Test Circuit

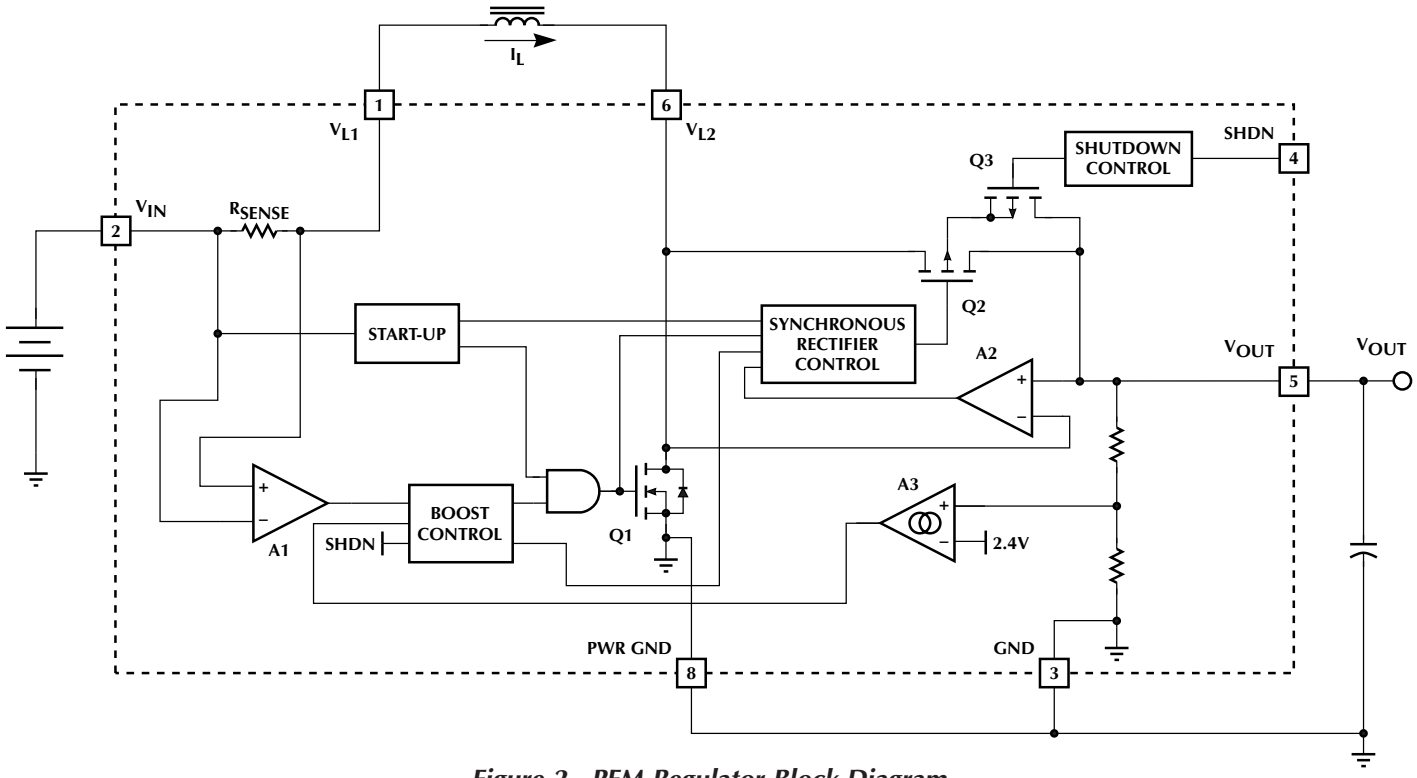


Figure 2. PFM Regulator Block Diagram

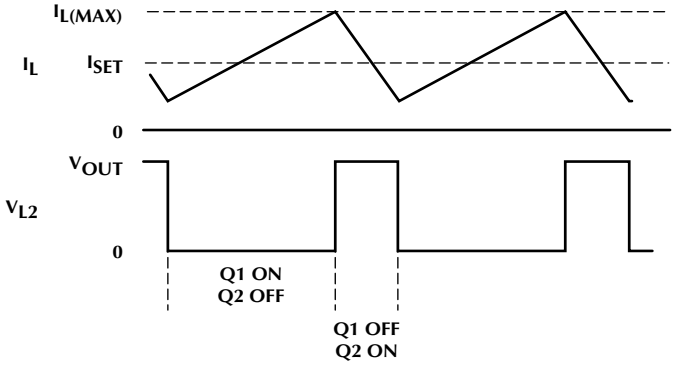


Figure 3. Inductor Current and Voltage Waveforms

FUNCTIONAL DESCRIPTION

The ML4870 combines a unique form of current mode control with a synchronous rectifier to create a boost converter that can deliver high currents while maintaining high efficiency. Current mode control allows the use of a very small high frequency inductor and output capacitor. Synchronous rectification replaces the conventional external Schottky diode with an on-chip P-channel MOSFET to reduce losses, eliminate an external component, and provide the means for load disconnect. Also included on-chip are an N-channel MOSFET main switch and current sense resistor.

REGULATOR OPERATION

The ML4870 is a variable frequency, current mode switching regulator. Its unique control scheme converts efficiently over more than three decades of load current. A block diagram of the boost converter including the key external components is shown in Figure 2.

Error amp A3 converts deviations in the desired output voltage to a small current, I_{SET}. The inductor current is measured through a current sense resistor (R_{SENSE}) which is amplified by A1. The boost control block matches the average inductor current to a multiple of the I_{SET} current by switching Q1 on and off. The peak inductor current is limited by the controller to about 1.3A.

At light loads, I_{SET} will momentarily reach zero after an inductor discharge cycle , causing Q1 to stop switching. Depending on the load, this idle time can extend to tenths of seconds. When the circuit is not switching, only 25µA of supply current is drawn from the output. This allows the part to remain efficient even when the load current drops below 250µA.

Amplifier A2 and the PMOS transistor Q2 work together to form a low drop diode. When transistor Q1 turns off, the current flowing in the inductor causes V_{L2} to go high. As the voltage on V_{L2} rises above V_{OUT}, amplifier A2 allows the PMOS transistor Q2 to turn on. In discontinuous operation, (where I_L always returns to zero), A2 uses the resistive drop across the PMOS switch Q2 to sense zero inductor current and turns the PMOS switch off. In continuous operation, the PMOS turn off point is independent of A2 and is determined by the boost control circuitry.

Typical inductor current and voltage waveforms are shown in Figure 3.

SHUTDOWN

The ML4870 output can be shut down by pulling the SHDN pin high (to V_{IN}). When SHDN is high, the regulator stops switching, the control circuitry is powered down, and the body diode of the PMOS synchronous rectifier is disconnected from the output. By switching Q1, Q2, and Q3 off, the load is isolated from the input. This allows the output voltage to be independent of the input while in shutdown.

DESIGN CONSIDERATIONS

OUTPUT CURRENT CAPABILITY

The maximum current available at the output of the regulator is related to the maximum inductor current by the ratio of the input to output voltage and the conversion efficiency. The maximum inductor current is limited by the boost converter to about 1A. The conversion efficiency is determined mainly by the internal switches as well as the external components, but can be estimated at about 80%. The maximum output current can be estimated by using the typical performance curves shown in Figures 4 and 5, or by calculation using the following equations:

$$I_{OUT(5V)} = 0.972 \times \left(\frac{V_{IN(MIN)}}{5V} \right) - 0.144A \quad (1)$$

$$I_{OUT(3.3V)} = 0.81 \times \left(\frac{V_{IN(MIN)}}{3.3V} \right) - 0.144A \quad (2)$$

Since the maximum output current is based on when the inductor current goes into current limit, it is not recommended to operate the ML4870 at the maximum output current continuously. Applications that have high transient load currents should be evaluated under worst case conditions to determine suitability.

INDUCTOR SELECTION

The ML4870 is able to operate over a wide range of inductor values. A value of 10µH is a good choice, but any value between 5µH and 33µH is acceptable. As the inductor value changes, the control circuitry will automatically adjust to keep the inductor current under control. Choosing an inductance value of less than 10µH will reduce the component's footprint, but the efficiency and maximum output current may drop.

It is important to use an inductor that is rated to handle 1.5A peak currents without saturating. Also look for an inductor with low winding resistance. A good rule of thumb is to allow 5 to 10mΩ of resistance for each 1µH of inductance.

The final selection of the inductor will be based on trade-offs between size, cost and efficiency. Inductor tolerance, core and copper loss will vary with the type of inductor selected and should be evaluated with a ML4870 under worst case conditions to determine its suitability.

Several manufacturers supply standard inductance values in surface mount packages:

Coilcraft	(847) 639-6400
Coiltronics	(561) 241-7876
Dale	(605) 665-9301
Sumida	(847) 956-0666

DEISGN CONSIDERATIONS (Continued)

OUTPUT CAPACITOR

The output capacitor filters the pulses of current from the switching regulator. Since the switching frequency will vary with inductance, the minimum output capacitance required to reduce the output ripple to an acceptable level will be a function of the inductor used. Therefore, to maintain an output voltage with less than 100mV of ripple at full load current, use the following equation:

$$C_{OUT} = \frac{44 \times L}{V_{OUT}} \quad (3)$$

The output capacitor's Equivalent Series Resistance (ESR) and Equivalent Series Inductance (ESL), also contribute to the ripple. Just after the Q1 turns off, the current in the output capacitor ramps quickly to between 0.5A and 1.3A. This fast change in current through the capacitor's ESL causes a high frequency (5ns) spike to appear on the output. After the ESL spike settles, the output still has a ripple component equal to the inductor discharge current times the ESR. To minimize these effects, choose an output capacitor with less than 10nH of ESL and less than 100mΩ of ESR.

Suitable tantalum capacitors can be obtained from the following vendors:

AVX	(207) 282-5111
Kemet	(846) 963-6300
Sprague	(207) 324-4140

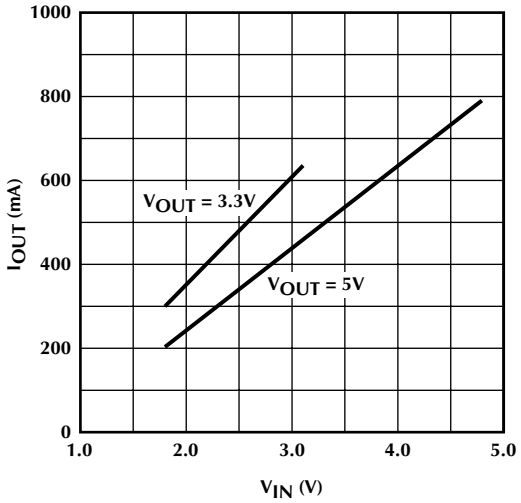


Figure 4. I_{OUT} vs. V_{IN} Using the Circuit of Figure 8

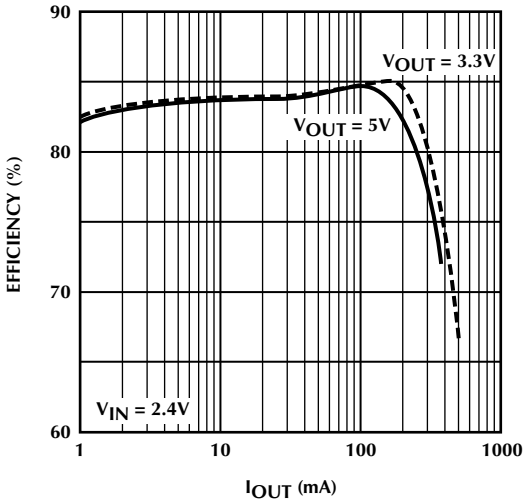


Figure 5. Efficiency vs. I_{OUT} Using the Circuit of Figure 8

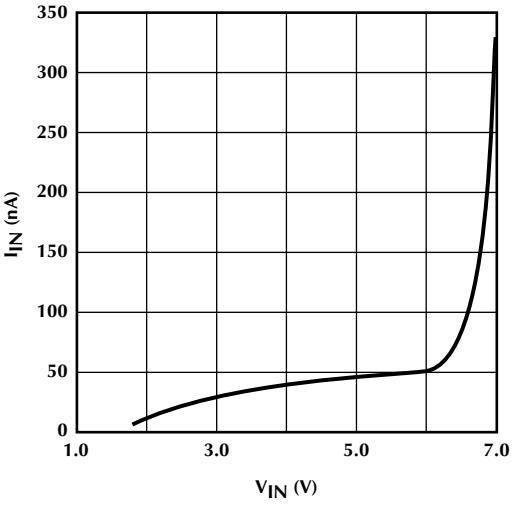


Figure 6. Input Leakage vs. V_{IN} in Shutdown

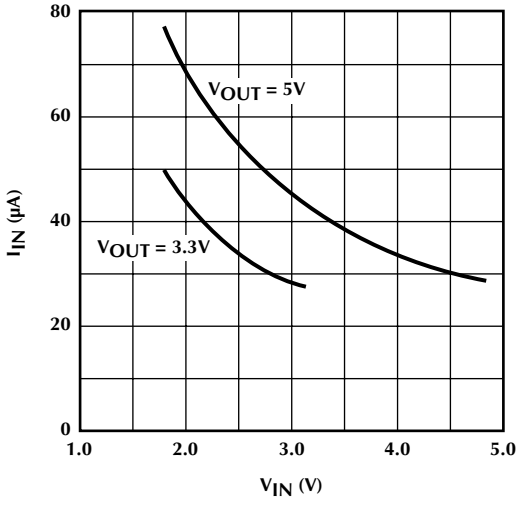


Figure 7. No Load Input Current vs. V_{IN}

DEISGN CONSIDERATIONS (Continued)

INPUT CAPACITOR

Due to the high input current drawn at startup and possibly during operation, it is recommended to decouple the input with a capacitor with a value of 47µF to 100µF. This filtering prevents the input ripple from affecting the ML4870 control circuitry, and also improves the efficiency by reducing the I^2R losses during the charge cycle of the inductor. Again, a low ESR capacitor (such as tantalum) is recommended.

It is also recommended that low source impedance batteries be used. Otherwise, the voltage drop across the source impedance during high input current situations will cause the ML4870 to fail to start-up or to operate unreliably. In general, for two cell applications the source impedance should be less than 200mΩ, which means that small alkaline cells should be avoided.

SHUTDOWN

The input levels of the SHDN pin are CMOS compatible. To guarantee proper operation, SHDN must be pulled to within 0.5V of GND or V_{IN} to prevent excessive power dissipation and possible oscillations. A graph of input leakage current while in shudown is shown in Figure 6.

LAYOUT

Good layout practices will ensure the proper operation of the ML4870. Some layout guidelines follow:

- Use adequate ground and power traces or planes
- Keep components as close as possible to the ML4870
- Use short trace lengths from the inductor to the V_{L1} and V_{L2} pins and from the output capacitor to the V_{OUT} pin
- Use a single point ground for the ML4870 PWR GND pin and the input and output capacitors, and connect the GND pin to PWR GND using a separate trace
- Separate the ground for the converter circuitry from the ground of the load circuitry and connect at a single point

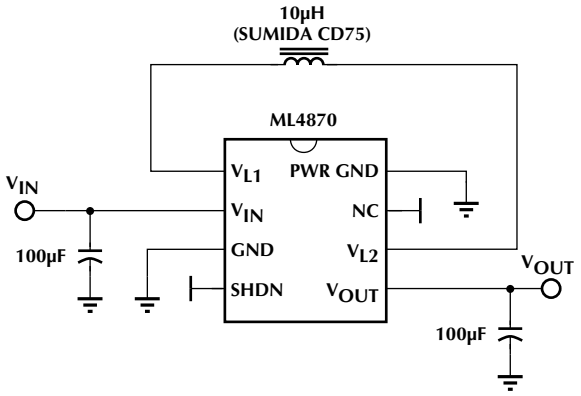


Figure 8. Design Example Schematic Diagram

DESIGN EXAMPLE

In order to design a boost converter using the ML4870, it is necessary to define the values of a few parameters. For this example, we have assumed that V_{IN} = 3.0V to 3.6V, V_{OUT} = 5.0V, and $I_{OUT(MAX)}$ = 400mA

First, it must be determined whether the ML4870 is capable of delivering the output current. This is done using Equation 1:

$$I_{OUT(MAX)} = 0.972 \times \left(\frac{3.0V}{5.0V}\right) - 0.144 = 439mA$$

Next, select an inductor:

As previously mentioned, it is the recommended inductance is 10µH. Make sure that the peak current rating of the inductor is at least 1.5A, and that the DC resistance of the inductor is in the range of 50 to 100mΩ.

Finally, the value of the output capacitor is determined using Equation 3:

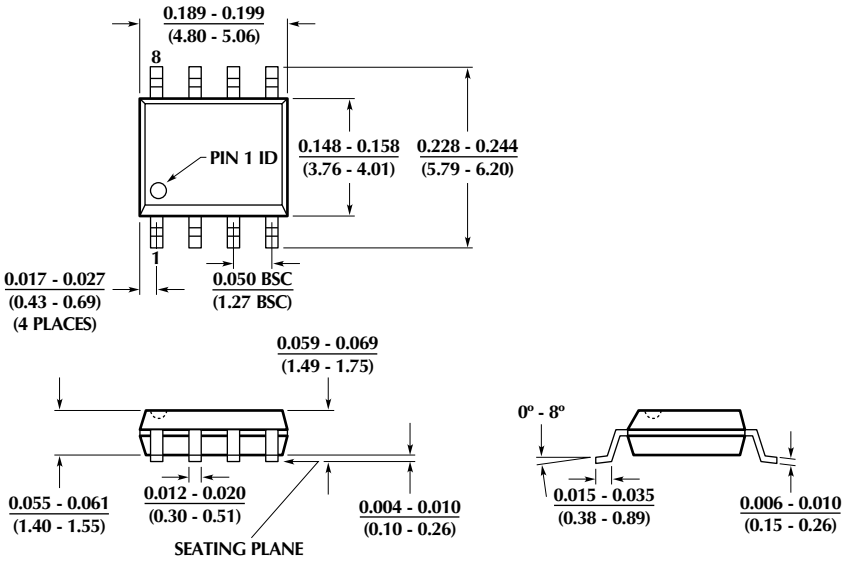
$$C_{OUT} = \frac{44 \times 10\mu H}{5.0V} = 88\mu F$$

The closest standard value would be a 100µF capacitor with an ESR rating of 100mΩ. If such a low ESR value cannot be found, two 47µF capacitors in parallel could also be used.

The complete circuit is shown in Figure 8. As mentioned previously, the use of an input supply bypass capacitor is strongly recommended.

PHYSICAL DIMENSIONS inches (millimeters)

Package: S08
8-Pin SOIC



ORDERING INFORMATION

PART NUMBER	OUTPUT VOLTAGE	TEMPERATURE RANGE	PACKAGE
ML4870CS-3	3.3V	0°C to 70°C	8-Pin SOIC (S08)
ML4870CS-5	5V	0°C to 70°C	8-Pin SOIC (S08)
ML4870ES-3 (Obsolete)	3.3V	-20°C to 70°C	8-Pin SOIC (S08)
ML4870ES-5(Obsolete)	5V	-20°C to 70°C	8-Pin SOIC (S08)

DS4870-01

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2092 Concourse Drive
San Jose, CA 95131
Tel: (408) 433-5200
Fax: (408) 432-0295
www.microlinear.com

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